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"High-power laser oscillation test using ceramic waveguide"

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by

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14. ABSTRACT
- Solutions to thermal problems such as temperature gradients and thermal lensing inside laser gain media are indispensable for high-power laser oscillation. This report details using ceramic bonding technology to fabricate ceramic waveguide (YAG-Nd:YAG-YAG) laser elements larger than previously described, and a preliminary investigation into their laser oscillation properties. The laser active layer (e.g., Nd:YAG, 400 ?m thickness) was arranged at the center, and low refractive index materials (high thermal conductive material: pure YAG with 400 ?m thickness) was strongly bonded at the atomic level to both faces. Sapphire was used as waveguide cladding (YAG-Nd:YAG-YAG) for higher total internal reflection. In order to investigate the optical quality of the core layer, a monolithic structure Nd:YAG slab was prepared with similar dimensions as the waveguide sample. For laser output power scaling, a newly designed sample holder was fabricated that allowed cooling ability up to around 700 W. Laser oscillation experiments will be performed once coated samples are available.

15. SUBJECT TERMS
Lasers, Materials and Devices, Transparent Ceramics, Transparent Polycrystalline Material, Waveguide Ceramics, Bonding Technology

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Title of Project: "High-power laser oscillation test using ceramic waveguide"

Abstract

Solutions to thermal problem such as temperature gradient and thermal lensing inside laser gain media are indispensable for high-power laser oscillation. In this work, we fabricated ceramic waveguide (YAG-Nd:YAG-YAG) laser elements larger than the previous samples, and investigated their laser oscillation properties. Based upon the results of this work, high-power laser oscillation test was performed using ceramic waveguide samples.

Keywords: Transparent ceramics, transparent polycrystalline material, waveguide ceramic, bonding technology

1. Introduction

Thermo-mechanical issue is very serious in high-power laser generation. Advantage of the waveguide type laser is the cooling from the large surface, which could suppress thermal gradient inside the core (waveguide layer). And, the long propagation length of pumping beam can generate laser output power effectively (high-gain and high-efficiency). Therefore, high output laser oscillation can be expected from a small laser gain medium with a waveguide structure.

Dr. Kamimura has performed the fundamental evaluation of the laser property on the waveguide sample which was produced from Dr. Ikesue. A ceramic waveguide sample shown in figure 1 was investigated for the evaluation of fundamental laser oscillation. A sample with 32mm length was pumped using two LDs of wavelength 808nm (maximum total output is 860 W). The thickness of the core layer (Nd:YAG) was 400μm. TIR (total inertial reflection) with the long propagation length of pumping beam can generate laser output power effectively (high-gain and high-efficiency). For this purpose, sapphire was used for cladding the three layers of core (YAG-Nd:YAG-YAG) from top and bottom (see Fig. 1).

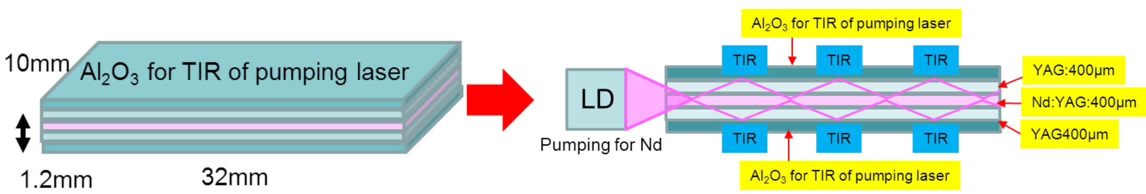


Fig 1. Design of the waveguide sample.

AR coating was put for all edge faces of the sample. Two TEC (200W/1 unit) which are attached up and down of the sample holder was used for the cooling of the sample. The transmittance of O. C. was 20%. Output of 266W was obtained from a sample with 0.6%Nd:YAG core layer. Around 50% of slope efficiency was achieved. Saturation of the laser output occurred in this experiment due to thermal factor (insufficient cooling condition), which was not because of the quality of the sample. Higher power-scaling will be possible by introducing higher power cooling system for the laser gain medium and adding additional LD stacks.

2. Objective of the project

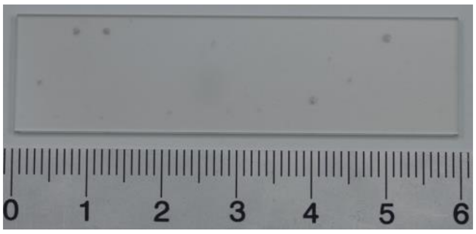
The objective of the project is to fabricate relatively larger size waveguide sample (YAG-Nd:YAG-YAG) with a certain length that multiple LDs can pump in and to investigate their laser oscillation properties. Material team will fabricate waveguide structure by using Nd:YAG and YAG ceramics. Bonding technology is the key technology to realize a planar waveguide structure with YAG materials. Laser team will investigate their laser oscillation property under sufficient cooling system for the laser gain media.

3. Project schedule and targets

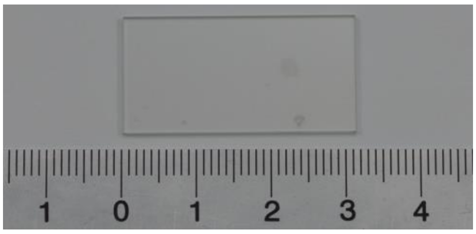
The project will on the fabrication of waveguide structure, and investigate their laser oscillation property. Waveguide sample fabrication and its evaluation will be involved; (1) fabrication of relatively larger waveguide sample (YAG-Nd:YAG-YAG) than previous project, (2) preparation of light focusing system for multiple LDs which is necessary for high power laser generation and sufficient cooling system for waveguide laser gain media, (3) evaluation of the performance of the waveguide laser at high-power laser oscillation.

4. Fabrication of waveguide laser

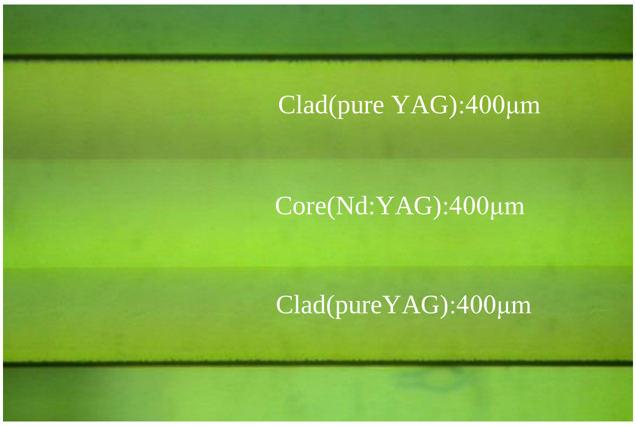
Power scaling will be performed using multiple LDs for high power laser oscillation. As for 32mmx16mmx1.2mmt sample, it will be pumped with one LD from left and another one LD from right side toward the end faces (16mmx1.2mmt). As for 62mm x 16mm x 1.2mmt sample, it will be pumped with two LDs from one end (62mmx1.2mmt) and with another two LDs from opposite end (62mmx1.2mmt). Thickness of core layer (Nd:YAG) is 400um and concentration of Nd^{3+} is 0.6%. By using ceramic bonding technology, three layer waveguide sample (YAG-Nd:YAG-YAG) was prepared by the following steps. We prepared two YAG ceramic slices with one surface polished and one Nd: YAG ceramic slice with both surfaces polished. After Nd:YAG ceramic slice was sandwiched with the two YAG ceramic slices, the stacked sample was heated over 1000 degree Celsius. Waveguide ceramic samples were successfully fabricated by using a ceramic bonding technology. In order to investigate the optical quality of the core layer (Nd:YAG), a monolithic structure Nd:YAG slab was prepared with similar dimension as the waveguide sample. All of ceramic sample used in this project were manufactured by Dr. Ikesue of world laboratory Co., Ltd. The photograph of a fabricated sample is shown in figure 2(a) and (b). A laser active layer (e.g., Nd:YAG with 400 μm thickness and 0.6 at% doping) is arranged at the center, and low refractive index materials (high thermal conductive material: pure YAG with 400 μm thickness) is strongly bonded at the atomic level on both faces of it. Each thickness of pure YAG is 400 μm. As a result, the thickness of the whole sample becomes 1.2 mm. From a micro photography, the interfacial condition bonded together is excellent (Fig. 2(c)). In this experiment, gradient processing (3 degree and 4 degree) was made on 16 mm x 1.2 mm surfaces to prevent ASE in the pumping direction.



(a)62mm x 16mm x 1.2mmt



(b)32mm x 16mm x 1.2mmt



(c)

Fig. 2(a), (b) Photograph of the sample with 400 μm thickness core, (c) Micro photography of the bonding boundary surface.

5. High-power laser oscillation using ceramic waveguide

For power scaling of the laser output, a sample holder was newly designed and fabricated. Up to 4 LD stacks of 808nm were prepared for a laser oscillation experiment as a pumping laser light. Maximum output per one LD unit is approximately 400 W. The prepared LDs were attached with 15mm intervals to the light focusing unit (see Fig.3).

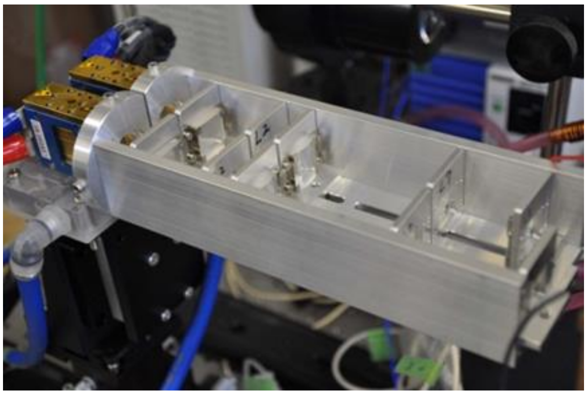


Fig. 3. Focusing unit for two LD stacks arranged with 15 mm width.

As for the pump beam, the vertical direction was focused in the sample inside by a focusing unit, and the horizontal made a collimated beam. A vertical focusing condition was adjustable from 400 μm to 1000 μm. The horizontal beam can propagate up to about 70 mm in parallel light with width of 9 mm. Figure 4 shows experimental arrangements for pumping with two LDs and four LDs. For the sample length of the resonance direction around 16mm, two LD stacks (total output: 800 W) are used for pumping. Furthermore, when the sample length of the resonance direction is around 62mm, four LDs (total output: 1,600 W) are used for pumping by two from right and two from left.

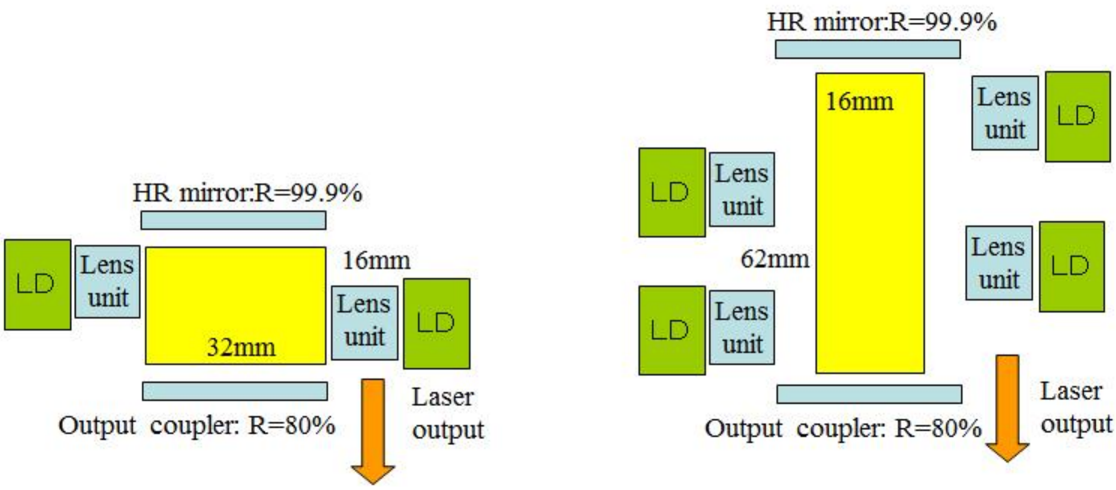


Fig. 4. Experimental arrangements for pumping with two LDs and four LDs

The waveguide sample was attached in a copper heat sink by using heat conduction grease. The heat sink cooled off by using up to 4 thermo-electronic coolers (200 W/ per unit). Cooling ability of TEC can be increased to up to around 700 W. A resonator was constituted by putting the sample between two flat mirrors. A mirror of 20 % of transmittance was selected as an output coupler (O. C.). Currently, preliminary tests for AR and HR coating on side faces of the waveguide sample are underway. AR coating for 808nm will be put on both end faces for LD pumping. As for oscillation direction, both ends will be AR and HR coated for 1064nm. Once the coated samples are ready, laser oscillation experiments will be performed subsequently.

6. Conclusions

High-power laser oscillation from ceramic waveguide was performed in this project. We have successfully fabricated a relatively larger waveguide ceramics than previous ones by using a ceramic bonding technology. A laser active layer (e.g., Nd:YAG with 400 μm thickness and 0.6 at% doping) was arranged at the center, and low refractive index materials (high thermal conductive material: pure YAG with 400 μm thickness) was strongly bonded at the atomic level on both faces of it. Sapphire was used as cladding the waveguide (YAG-Nd:YAG-YAG) for higher total internal reflection. In order to investigate the optical quality of the core layer (Nd:YAG), a monolithic structure Nd:YAG slab was prepared with similar dimension as the waveguide sample. As for 32mmx16mmx1.2mmt sample, it will be pumped with one LD from left and another one LD from right side toward the end faces (16mmx1.2mmt) with up to 800W pumping power. As for 62mm x 16mm x 1.2mmt sample, it will be pumped with two LDs from one end (62mmx1.2mmt) and with another two LDs from opposite end (62mmx1.2mmt) with up to 1600W pumping power. For power scaling of the laser output, a sample holder was newly designed and fabricated. Cooling ability of TEC can be increased to up to around 700 W by using high-power TEC units. Once the coated samples are ready, laser oscillation experiments will be performed subsequently.

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List of Publications

"All ceramic Nd:YAG waveguide laser element with perfect bonding condition (Invited Paper)", Photonics West 2012.